

International Space Station Research for the Next Decade: International Coordination and Research Accomplishments

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During 2011, the International Space Station reached an important milestone in the completion of assembly and the shift to the focus on a full and continuous utilization mission in space. The ISS partnership itself has also met a milestone in the coordination and cooperation of utilization activities including research, technology development and education. We plan and track all ISS utilization activities jointly and have structures in place to cooperate on common goals by sharing ISS assets and resources, and extend the impacts and efficiency of utilization activities. The basic utilization areas on the ISS include research, technology development and testing, and education/outreach. Research can be categorized as applied research for future exploration, basic research taking advantage of the microgravity and open space environment, and Industrial R&D / commercial research focused at industrial product development and improvement. Technology development activities range from testing of new spacecraft systems and materials to the use of ISS as an analogue for future exploration missions to destinations beyond Earth orbit. This presentation, made jointly by all ISS international partners, will highlight the ways that international cooperation in all of these areas is achieved, and the overall accomplishments that have come as well as future perspectives from the cooperation. Recently, the partnership has made special efforts to increase the coordination and impact of ISS utilization that has humanitarian benefits. In this context the paper will highlight tentative ISS utilization developments in the areas of Earth remote sensing, medical technology transfer, and education/outreach.

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During 2011, the International Space Station reached an important milestone in the completion of assembly and the shift to the focus on a full and continuous research mission in space. As an international partnership, we plan and track all ISS utilization activities jointly and have structures in place to cooperate on common goals by sharing ISS assets and resources, and extend the impacts and efficiency of utilization activities. The basic utilization areas on the ISS include research, technology development and testing, and education/outreach. Research can be categorized as applied research for future exploration, basic research taking advantage of the microgravity and the space environment, and Industrial R&D / commercial research focused on product development and improvement. Technology development activities range from testing of new spacecraft systems and materials to the use of ISS as an analogue for future exploration missions to destinations beyond Earth orbit. This presentation by the ISS Programme Science Forum comprising all ISS international partners, will highlight the ways that international cooperation in all of these areas is achieved, and the overall utilization accomplishments as well as future perspectives stemming from international cooperation on the ISS. Recently, the partnership has made special efforts to increase the coordination and impact of ISS utilization that has humanitarian benefits. We have identified ISS utilization objectives in the areas of Earth remote sensing, medical research and technology transfer, and education/outreach to achieve these enhanced goals in addition to our individual national objectives.

INTRODUCTION

The International Space Station (ISS) is an international collaboration between the Canadian Space Agency (CSA), European Space Agency (ESA), Japan Aerospace Exploration Agency (JAXA), Federal Space Agency of Russia (Roscosmos) and the National Aeronautics and Space Administration (NASA). Over the past two decades, this international partnership has

worked together to build the ISS, conduct scientific research and test technology concepts.

The partnership reached a significant milestone in May 2011 with the completion of the vehicle assembly phase of the ISS. Focus for the ISS is now on the full and continuous use of the orbiting laboratory for research, technology development and education/outreach activities.

RESEARCH ON THE ISS

The partnership plans, implements and tracks the research, technology demonstration and educational/outreach activities that occur on the ISS. These activities are broken into the following six categories: biology and biotechnology, Earth and space science, educational and cultural activities, human research, physical science, and technology development and demonstration.

Even before the first permanent crew inhabited the ISS, scientific investigations were conducted. The first investigations began in December 1998 –almost two years before the Expedition 1 crew arrived. From December 1998 through March 2011, over 1100 investigations have been conducted and of these, approximately 87% of the investigations have been completed or considered permanent installations. (Figure 1)

The ISS offers a unique environment for scientists from around the world to conduct investigations. To date, more than 1300 researchers from 63 countries have participated in ISS research. (Figure 2)

The environment of microgravity and other space conditions provides a unique lab environment for experiments that cannot be reproduced on Earth—experiments where the effect of gravity is controlled as an experimental variable. The breadth of research this enables is unique among research platforms.

Biology and Biotechnology Advances in biological research, such as genomic research and sequencing of the human genome, have led to the 21st century being deemed as the “era of biology”^[1]. Throughout the history of the ISS, more than 500 biological investigations have been conducted. This portfolio covers a broad spectrum of activities such as protein crystal growth, cell and integrated biology, plant physiology, vaccine development to name a few.

Earth and Space Science The ISS contains multiple instruments from several countries that observe the Earth and space. More instruments are planned so that by about 2015 most of the 24 external instrument sites on ISS will be occupied ^[2]. These instruments range from permanent fixtures mounted externally on the ISS to handheld cameras used by the crew to capture events such as large storms and disaster areas. To date, over 40 Earth and space observation investigations have been conducted from the ISS.

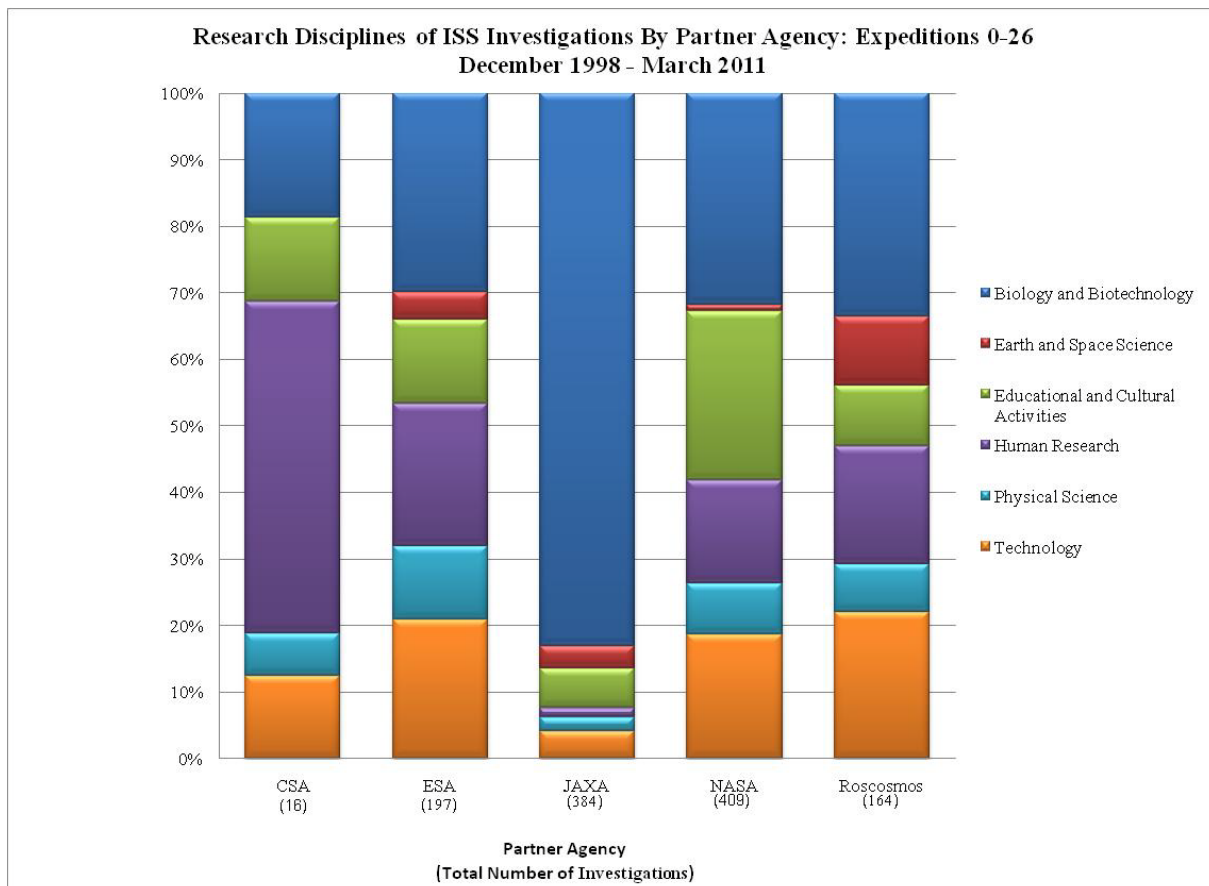


Figure 1 Number of investigations conducted on the ISS through March 2011

Educational and Cultural Activities Inspiring the next generation of scientists and engineers is a common goal of the ISS partner agencies. Nearly 170 dedicated educational investigations have been conducted on the ISS. Many of the educational activities on the ISS involve crewmembers demonstrating scientific concepts such as Newton's Law, providing challenges for

investigations done on the ISS. To date, 75 investigations have been operated with nearly 40 planned to operate over the next year.

Technology Development and Demonstration Over the course of the past 12 years, over 170 technology development and demonstration investigations have operated on the ISS. The orbiting laboratory is an ideal

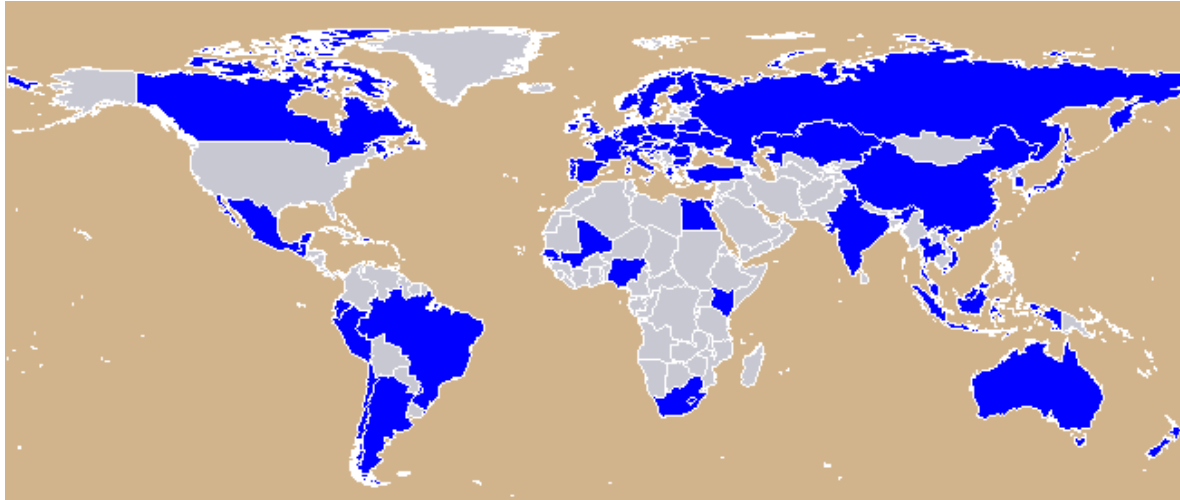


Figure 2 Highlighted countries have participated in research or educational activities on the ISS

students to have their experiments conducted on ISS, and conducting ham radio passes with the crew and students from around the world. Cultural activities impact not only students but individuals of all ages. There have been several cultural activities over the recent years. One inspiring creative writing activity had participants provide poems to create a poem chain that had entries from the crewmembers on the ISS. The fourth Space Poem Chain was initiated by Soichi Noguchi onboard the ISS and was completed on 4 March 2011^[3].

Human Research The space environment provides an opportunity to examine human health in ways that cannot be done on Earth^[1]. To date, over 140 biomedical investigations on human health have been accomplished. The research that is conducted on the ISS has the potential to benefit patients on Earth in such area as cardiovascular diseases, immunology, bone loss, nutrition, cancer studies, ocular health and telemedicine capabilities in remote areas of Earth and this paper will review some of the latest information in this area.

Physical Science In the microgravity environment, there is opportunity to remove or allow gravity as an experimental factor from physical science investigations ranging from fluid flow to particle physics to combustion. Over the last year, the availability of major facilities for fluids, combustion, and materials science led to rapid increases in the number of physical science

locale to test a variety of new technologies that can be used for future space exploration and here on Earth. The demonstrations range from robotics to environmental monitoring to imaging technology.

Tracking Research

The ISS partner agencies have a joint database that is used to track investigations from beginning until the final results paper is published. In this database, each investigation is represented with a summary that details the science objectives, the time period of operations, the crew operations for the investigation, publication of the results of the research, investigator information and images of the investigation^[4]. Each ISS partner remains the primary source of the information and maintains this information for the public on their own hosted webpages. In addition, NASA provides a set of index pages that can serve as an integrated gateway for the partnership to find the information about each investigation.

INTERNATIONAL PARTNERSHIP

The international partnership of the ISS is governed by the five International Partners (CSA, ESA, JAXA, NASA and Roscosmos). The partnership encourages international collaborations on scientific investigations. Many of the facilities that are onboard the ISS are shared between the agencies.

One such facility is the ESA sponsored European Modular Cultivation System (EMCS) which is accommodated in an EXPRESS rack of NASA in the *Columbus* module. This facility allows for the cultivation, stimulation and crew-assisted operations of biological investigations under controlled conditions. The EMCS uses experiment containers that are capable of supporting a variety of organisms such as worms and flies to seed and plants^[5]. To date, ESA, JAXA and NASA have all used this facility to support plant growth investigations (Figure 3). Over the coming year, new investigations with related scientific objectives that use the EMCS are being implemented cooperatively by ESA and NASA.



Figure 3 ISS crewmember replacing the European Modular Cultivation System (EMCS) Experiment Container (EC) in the *Destiny* laboratory of the International Space Station. Image courtesy of NASA.

Another facility with significant cooperation is the NASA's Materials Science Research Rack (MSRR) which is accommodated in *Destiny* and hosts ESA's Material Science Laboratory (MSL). ESA supports several large international science teams that use this facility to study and improve the formation of metal alloys. NASA-sponsored investigators have collaborated with these teams, with 13 samples processed to date as part of the CETSOL and MICAST investigations (Columnar-to-equiaxed transition in solidification processing and microstructure formation in casting of technical alloys under diffusive and magnetically controlled convective conditions) in the MSL.

The radiation phantom MATROSHKA has already been used for many years at various locations outside and inside of ISS modules and the acquired radiation data has been provided to European, Russian, Japanese and US scientists.

The Alpha Magnetic Spectrometer-02 (AMS-02) was installed on the ISS on 19 May 2011. (Figure 4) This state-of-the-art particle physics detector is designed to measure cosmic rays as a key advance in the search

for antimatter and to gain an understanding of the nature of dark matter. Since activation of the AMS-02, the instrument team has reported that more than two billion events have been detected^[6]. This investigation is an international collaboration with participants from 16 different countries, led by Nobel Laureate Samuel Ting.

Another major future ISS payload with significant international science cooperation will be ACES (Atomic Clocks Ensemble in Space) where tentatively worldwide ground reference clocks will be tied into an integrated system to enhance the accuracy in the time and frequency domain which is of importance for navigation applications but also yields fundamental physics insights.



Figure 4 The Alpha Magnetic Spectrometer-02 on the International Space Station. Image courtesy NASA.

The ISS is clearly going to be an important platform for astrophysics research. For example, data from the JAXA MAXI instrument on ISS (Monitoring All-sky X-ray Imager) was combined with data from the Swift satellite in the first documented observation of a super massive black hole consuming a star. Although the Swift team was first to report a gamma-ray burst from Swift J1644+57, the MAXI instrument was able to provide observations of the event several hours prior to the Swift observations. The data were combined to improve the standard error around the power estimates of the event, and both teams co-authored their finding in *Nature*^[7].

BENEFITS TO HUMANITY

The ISS benefits to Earth extend far beyond the partnership of nations that built the laboratory and lead its use. These benefits are readily transferred around the world and can be grouped in three main themes; Earth observation, human health and education/outreach. Collaboration among partner and non-partner nations is extensive with over 63 countries participating in some aspect of ISS research or education activities.

Earth Observation The ISS has been used as an observation platform with photography since the first permanent crew arrived in 2000. Several different observation investigations observe hurricanes/typhoons, environmental changes, atmospheric changes, agricultural areas, and natural disasters such as floods and fires.

The Crew Earth Observations (CEO) investigation captured the aftermath of the devastating tsunami that Japan experienced in March 2011. The crew onboard the ISS were able to capture images of the northern coast of Japan two days after the disaster^[8] (Figure 5).



Figure 5 Northern coast of Japan from the International Space Station two days after the devastating tsunami. Image courtesy NASA.

With assembly complete, the outfitting of the many external platforms for automated observations is being fully defined. Some of these instruments for understanding the Earth and its climate, and for rapid response to disasters and dynamic events to be added include ESA instruments for the observation of solar irradiance (SOLAR), a US hyperspectral instrument (HICO, Hyperspectral Imager for the Coastal Ocean), and an instrument for monitoring agricultural productivity (ISSAC). NASA's SERVIR project will be extended to ISS with a new instrument, I/SERV to operate in the optical-quality window facility (the Window Observational Research Facility, WORF). JAXA has developed new capabilities for an extremely sensitive high definition video handheld by the crew, helping the public to better understand dynamic events when they occur, with the first in-cabin downlink tested in July 2011.

Human Health Research is used to identify the health risks from living in space, and identify ways to protect crew health during exploration missions. New knowledge gained from medical research in orbit can come back to earth in very concrete ways. Some examples of these benefits are vaccine development, bone loss countermeasures, remote ultrasound imaging,

and research on wound healing, immunology and cardiovascular health.

ISS is being used as a platform for vaccine development by two different teams. Astrogenetix, Inc., has used ISS assembly missions for a microgravity model of virulence to help in the screening of potential vaccines for *Salmonella* food poisoning and for methicillin-resistant *Staphylococcus aureus* (MRSA). Arizona State University Biodesign Institute has conducted spaceflight tests aimed at improving the effectiveness of a vaccine for pneumonia that is currently in clinical trials.

Over the past year, a drug (ProliaTM) that had been tested in space during ISS assembly missions came on the market. The drug is now approved in the U.S. for use in cases of severe bone loss in patients on Earth. The use of animal models in space complemented the clinical trials with added insights into drug function.

Correlative data from studies of nutrition and biomarkers in astronauts identified that those ISS astronauts who consumed more fish had less bone loss. The possible role of omega-3 fatty acids from a fish-based diet was further confirmed in bed rest and *in vitro* studies^[9]. Such data benefit not only the health of astronauts, but may influence the treatment of osteoporosis on Earth.

The first major findings have been published on a optical changes affecting the vision of astronauts after long-duration spaceflight. Changes in vision were documented for over 60% of long-duration astronauts compared to 29% of short-duration astronauts, and the effects range from a decrease in vision spherical equivalent refraction from +0.50 to +1.75 diopters^[10]. Space medicine experts are still evaluating hypotheses about the cause of the optical changes. This work illustrates the importance of ISS as the place to study the health effects of long-duration spaceflight. It also shows how research in a new environment can lead to unexpected effects and insights into disease processes.

Technology to allow remotely-guided ultrasound to be performed by non-specialist operators^[11] continues to be applied around the world. Most recently, the approach has been used in remote areas of Africa to identify pregnant women in need of transport to neonatal care facilities before they go into labor, decreasing the risk to both mother and child. The approach has also been adopted by the American College of Surgeons as a training tool for residents.

The technology developed for water purification on the ISS has been adapted for use in areas where clean

water isn't accessible. The microbial check valves from the ISS water processor assembly, which is used to produce drinking water for the crew, has been developed into a water filtration solution by Water SecurityTM Corporation. This filtration system has been deployed in disaster areas around the world, including Mexico, Iraq and Pakistan^[12].

Education Inspiring students of all ages to pursue careers in science, technology, education and mathematics (STEM) is a common goal of each of the partner agencies. There are many educational outreach opportunities stemming from the scientific and engineering activities on the ISS.

The Amateur Radio on the International Space Station (ARISS) investigation allows children from around the world to speak directly with crewmembers on the ISS using ham radio. Students prepare for the contact with ISS by learning about the space station and how amateur radio operates. The students develop questions for the crew, ranging from how they live in space to science-themed inquiries. ARISS has initiated more than 600 contacts with the ISS letting thousands of students from over 40 countries talk with the ISS crew.

Hundreds of thousands of students from around the world viewed web video of a set of spiders that dwelled on the ISS as part of an online curriculum developed by BioEd Online. In their classrooms, students carried out parallel investigations in non-space conditions and learned about the scientific method.

The NASA-sponsored Kids in Micro-G initiative allowed students from around the US to develop their own ISS experiments using a set of readily available materials. After two successful years as an American initiative, the project is being expanded through a partnership with Google/YouTube and Space Adventures to reach students worldwide. Look for the next contest announcement in Fall 2011.

ISS partners are currently conducting a comprehensive survey of the diverse educational activities on the ISS, as well as the educational content stemming from other research projects. A summary of these impacts is expected to be completed in 2012.

CONCLUSION

The ISS began its journey in 1998 with launch of the first component and completed assembly in 2011. Even during this resource-constrained, assembly-active period, over 1100 research and technology investigations were conducted. With vehicle assembly

complete, the "Era of Utilization" begins, using the orbiting laboratory to its full potential^[13].

Through the history of the ISS, the international partnership has planned, implemented and tracked scientific investigations and engineering feats. This partnership continues to encourage active collaboration between countries and investigators to maximize the research output and efficiency of use of this unique resource.

The benefits to humankind are being revealed as the results from ISS research are published and increased knowledge is applied to research, technologies, and products. The range of benefits is vast from climate monitoring to improving human health to encouraging students of all ages to achieve their goals and embrace science, technology and mathematics..

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